Answer Key

If you have any questions, please contact Aditya Shah/Seven Lakes High School!

1. (a) Planetary Nebula
   (b) A or B
   (c) Smaller
   (d) K
   (e) 10
   (f) Mira/Pulsating Variable
   (g) N or O
   (h) 2
   (i) 14, 3, 12, 15, 13, and 1
2. (a) May 10th to May 14th (May 11th)
   (b) 12.3 to 12.7 (12.5)
   (c) -18.5 to -16.5 (-17.72 to -17.13)
   (d) β, the initial decline rate, is defined as the average slope of the light curve between t_{max} and t_{bend}. A steeper decline, that is, a larger $|\beta|$, means a less bright Type Ia supernova
   (e) Greater. β is the rate of decline, so a faster decline is represented with a larger positive number!
   (f) Use the distance modulus! 5.75×10^6 to 1.8×10^7 parsecs (8.4333×10^6 parsecs)
3. (a) 350 to 450 m/s (400 m/s)
   (b) This PNe is too far to have a parallax angle that can be accurately determined using modern technology!
   (c) This PNe is still in the Milky Way, which is too close for the Hubble relation to be of any use. Its motion through the galaxy and gravitational interactions with nearby objects will be more significant than the recession velocity caused by the expansion of the universe. You cannot assume that the redshift is caused completely by the expansion of the universe
   (d) Planetary Nebula Luminosity Function!
   (e) Exponential
   (f) The planetary nebula in this question is within the Milky Way, but the PNLF isn't well calibrated for the Milky Way. It's generally used to PNe in other galaxies, such as M31 and determines distances about 10Mpc away. The diameter of the Milky Way is about 0.3 Mpc
4. (a) Bigger PNe are fainter in the Hα band
   (b) Different shapes/types of PNe
   (c) No
   (d) Hα is a common line and there's abundant data in literature
   (e) Yes. Image 8 shows that this relation still holds whether the planetary nebula is in the Milky Way or not, so it is suitable for this planetary nebula.
   (f) First, measure the incoming Hα flux. Using the Hα S-r, find the corresponding value for radius. You already know the angular size of this object, so using the formula for angular size, one can easily find the distance!
   (g) Use the steps outlined in (f). 26000 to 34000 light years (29000-31600 light years)
   (h) Younger
   (i) 1300 to 2200 years old! (1690 years)
   (j) Planetary nebulae are relatively transient. After about 50,000 years, their material disperses into the ISM and planetary nebula has essentially disappeared! The aliens were viewing it after 100,000 years, which was long after the planetary nebula had gone.
5. (a) $2.7 \times 10^3 - 3.0 \times 10^3$ kpc (2.884×10^3 kpc)
   (b) $1.8 \times 10^3 - 2.1 \times 10^3$ kpc (2.041×10^3 kpc)
   (c) No
6. (a) Line A

(b) The center of mass of the binary star system
(c) Slightly less than two
(d) 45-55 years (50 years)
(e) Periastron
(f) Apastron
(g) 1935-1945ish
(h) 0.5

7. (a) 17.5-18.5 parsecs (18 parsecs)
(b) 15-25 AU (20 AU)
(c) 2.9-3.5 solar masses (3.2 solar masses)
(d) Star X has a mass of 2.2-2.8 (2.5) solar masses and Star Y has a mass of 0.5-0.9 (0.7) solar masses
(e) Star Y must be the white dwarf, because Star X's mass is above the Chandrasekhar Limit!
(f) J
(g) Yes